SYMPOSIUM ON METABOLISM OF INORGANIC COMPOUNDS[1]

I. Introduction

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The history of the bacterial metabolism of inorganic compounds dates back to the Golden Age of Microbiology and its early period is dominated by the genius of Sergei Winogradsky, who discovered in 1888 the oxidation of sulfide by species of *Beggiatoa* (10), isolated in 1890 the nitrifying bacteria (11), clearly defined the chemolithotrophic way of life, and demonstrated, in 1894, the fixation of free nitrogen by *Clostridium pasteurianum* (12). In the course of the same fruitful decade, the sulfate-reducing bacteria were isolated by Beierinck (1) in 1895 and bacterial denitrification was discovered by Dehérain (2) in 1897.

These major discoveries, which were to be completed shortly afterwards by the isolation of *Thiobacillus* species in 1902 (Nathanson, 6) and of the hydrogen bacteria in 1906 (Kaserer, 4) are still the firm basis of modern ideas on the biological cycles of nitrogen and sulfur in nature and on the essential role played by bacteria in the occurrence and continuation of life on the earth.

For many years, however, the relationships between bacteria metabolizing inorganic substances, especially chemoautotrophs, and other organisms remained somewhat obscure. The existence of strict autotrophs which grow only in mineral media and are apparently inhibited by traces of organic matter had led to the generally accepted postulate that the ability to metabolize inorganic compounds is restricted to a few primitive forms of life and involves biochemical mechanisms basically different from those of heterotrophic bacteria and higher organisms.

The studies of van Niel (8) on the photosynthetic bacteria and on the physiological role of sulfur oxidation in these organisms opened in 1931 a new chapter and the modern period in the study of inorganic metabolism. These investigations, which have greatly contributed to the elucidation of the photosynthetic mechanism in green plants as well as in bacteria, are a remarkable example of a microbiological contribution to biology in general.

Since the end of the last world war, the extensive progress of biochemical methods has made possible the investigation of the enzymatic pathways of inorganic metabolism, and the contributions presented at this Symposium illustrate some of the most important results already obtained along this line. One of the main achievements of these recent studies is that they have conclusively demonstrated the unity of biochemical systems in the phylogenic scale. They have shown that the chemolithotrophs and other bacteria metabolizing inorganic substrates perform their activities through enzyme systems and respiratory chains in which the cofactors and the cytochrome components are identical with or closely related to those of animals and plants. Moreover, it has been established that in all these organisms free energy is transferred from exergonic to endergonic reactions by adenosine triphosphate exchange and intermediary phosphorylations.

Another important finding is that the ability to metabolize inorganic substances is not restricted to a small number of bacterial species but also exists in higher organisms and even in mammals. In this regard recent advances in the field of sulfur metabolism provide some striking examples. As shown by Dr. Peck in his contribution to this Symposium, sulfate is metabolized by *Desulfovibrio desulfuricans* and by thiobacilli through enzymatic pathways which are partly identical to the mechanism of sulfate activation previously discovered by Wilson and Bandurski (9) and by Robbins and Lipmann (7) in yeast and mammalian liver. Similarly, Milhaud, Aubert, and Millet (5) have found in *Thiobacillus denitrificans* the same sulfite oxidase system

[1] This symposium was organized by Dr. Howard Gest under the auspices of the Division of General Bacteriology and presented at the Annual Meeting of the American Society for Microbiology in Chicago, Ill., on April 26, 1961. Dr. Jacques C. Senez served as honorary convener.

which was first demonstrated by Fridovitch and Handler (3) in dog liver.

Such observations have led to a much clearer view of the comparative biochemistry of the metabolism of inorganic substances. The chemolithotrophic bacteria appear now in many regards as "bridge organisms" sharing properties with both the animal and the vegetable kingdoms. This is especially evident with regard to the fixation of CO_2 which is performed by thiobacilli and hydrogenomonads simultaneously through a ribulose diphosphate carboxylase, as in plants, and through carboxylation of phosphoenol pyruvate, as in heterotrophic microorganisms and animals.

If the uniqueness of the bacteria metabolizing inorganic substances can no longer be attributed to the nature of their enzyme systems, this group has nevertheless some genuine and remarkable features. In higher plants and animals, the metabolism of inorganic compounds appears to have basically a biosynthetic function, as in assimilatory nitrate reduction, or a role in the excretion and detoxification of metabolic wastes, as is the case for sulfate activation and sulfite oxidation in mammals. In contrast, the bacteria include organisms which utilize inorganic substances as the exclusive energy sources (chemolithotrophs), as external electron donors for photosynthesis (photosynthetic sulfur bacteria), or as final electron acceptors for respiration (denitrifying and sulfate reducing bacteria). These ways of life in which inorganic matter participates in the main energetic metabolism are found only among bacteria and are a unique property of this group of organisms.

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